

Exploring Neutrinoless Double-Beta Decay in the Inverted Hierarchy Region with Bolometric Detectors

US-CUORE Collaboration

The observation of $0\nu\beta\beta$ decays (DBD) would unambiguously establish the violation of lepton number conservation, and indicate that neutrinos are Majorana particles, i.e. they are their own anti-particles. The rate of the process is sensitive to the effective Majorana neutrino mass. Determining whether neutrinos are Majorana or Dirac particles and measuring their masses are among the highest priorities in neutrino physics, as was pointed out in the 2004 APS Multi-Divisional Neutrino Study as well as the 2007 NSAC Long Range Plan. The answer will also have important implications for astrophysics and cosmology. Addressing this question has become an even higher priority since the recent apparent discovery of the long-sought Higgs boson. A Majorana neutrino mass is not generated by the Higgs mechanism and Majorana particles are not accommodated in the Standard Model. Thus, discovery of the Majorana nature of neutrinos would provide a clear indication of new physics beyond the Standard Model.

CUORE, the Cryogenic Underground Observatory for Rare Events, promises to be one of the most sensitive $0\nu\beta\beta$ experiments this decade. Using a bolometric array of 988 750-g crystals of natural TeO_2 , it will begin to explore the neutrino mass values in the so-called inverted mass hierarchy. CUORE is an established project within the DOE and NSF. The detector is currently under construction at the Laboratori Nazionali del Gran Sasso (LNGS) in Assergi, Italy, and is expected to start operations in 2014.

With the expected background of 0.01 counts/(keV kg year) and the energy resolution of 5 keV FWHM in the $0\nu\beta\beta$ region of interest, CUORE is projected to reach a sensitivity of $T_{1/2} > 1.6 \times 10^{26}$ years after five years of operation, which would correspond to a limit on the effective Majorana mass of the electron neutrino of $\langle m_{ee} \rangle < 41\text{--}95$ meV, depending on the estimate of the nuclear matrix element. By 2016-2017, after 2-3 years of operation, half-life limits of $T_{1/2} > 10^{26}$ years will be within reach, corresponding to $\langle m_{ee} \rangle < 52\text{--}120$ meV.

If $0\nu\beta\beta$ decay avoids detection at this level of sensitivity, the next logical milestone in the quest for unraveling the nature of neutrinos is an experiment with the sensitivity of $O(10$ meV) to the effective neutrino mass. Such an experiment would be able to either discover the Majorana nature of neutrinos or completely rule it out, should the neutrino masses be arranged in the inverted hierarchy. Given the expected constraints on the sum of the neutrino masses from cosmological observables and the future direct measurements of the neutrino mass hierarchy in the accelerator- and reactor-based oscillation experiments, a DBD measurement of such sensitivity starting around 2020 would be both timely and scientifically relevant. Should the hierarchy prove to be inverted, a DBD measurement with sensitivity of $O(10$ meV) would unambiguously prove the Majorana or Dirac nature of neutrinos. If the hierarchy is normal, an experiment with 10-meV sensitivity would be an important demonstration milestone towards the ultimate, definitive measurement. It would also be sensitive to non-standard sources of lepton number violation.

Reaching 10-meV effective mass sensitivity requires an experiment with nearly zero background, energy resolution of a few keV, and about a ton of active mass of an appropriate isotope. This can be achieved with a bolometric experiment like CUORE, with cost-effective upgrades. The required improvements would include: (a) isotopic enrichment of the element of choice; (b) active background rejection of alpha backgrounds on the surfaces of detector materials; (c) further reduction (compared to CUORE) in the gamma backgrounds by careful material and isotope selection and active veto of multi-site events; (d) improvements in energy resolution; and (e) further reduction in cosmogenically generated radioactive backgrounds by active muon veto and/or by operating at a deeper underground location.

The CUORE collaboration, both in the US and in Italy, is engaged in an active R&D program along all the directions outlined above. With the current support from the NSF and DOE, we are investigating the cost and purity of bolometric crystals highly enriched in ^{130}Te , studying background rejection with scintillation, Cherenkov radiation, ionization, and pulse-shape discrimination, testing novel materials and readout techniques. Experience with the CUORE assembly will allow us to further refine and optimize the process of putting together a 1-ton scale detector. Once CUORE is operational, we expect the vigor of these R&D activities to ramp up, with the goal of preparing a full proposal for an upgraded bolometric experiment with $O(10$ meV) Majorana mass sensitivity on the timescale of 2016. We foresee two scenarios: (A) a joint US-EU experiment sited at LNGS, along the lines of the CUORE project, with equal participation by both parties, or (B) an experiment sited in North America, with approximately 80% of the cost contributed by the US and the rest borne by international collaborators. Scenario (A) would take advantage of the existing infrastructure at LNGS, including the high-power dilution refrigerator; Scenario (B) would require additional investments but could take advantage of a deeper underground location, e.g. at SURF or SNOLab. In either scenario, US groups would maintain leadership positions in the quest for understanding the nature of neutrinos and the role of lepton number in Nature.